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Chirp signalling offers modulation scheme for underwater communications

Edit J. Kaminsky

Information contained in the slope of chirp signals can be employed for digital underwater acoustic communications across a broad range of applications.

Wireless communication can be conducted in the underwater acoustic (UWA) channel through sonar signalling. We propose using the frequency-vs-time slope of sonar 'chirps' to transmit information in a robust scheme for a spread-spectrum underwater communications system.

Digital data can be represented by the slope of chirp signals. In the simplest binary case, an 'up' chirp (i.e., a signal with instantaneous frequency that linearly increases with time) represents a '1' and a 'down' chirp represents a '0'. Higher-dimensional constellations can easily be obtained by using a larger number of up/down slopes. The wide bandwidth should provide immunity from signal degradation in the channel.

Underwater communications

Using a cable to establish communication between two remote underwater sites has several disadvantages. It is expensive to install and maintenance and repair are difficult, especially for communication in deep water. In addition, drag on the cable can be a problem if the user is small and mobile. Sound propagated through water is a better solution. However, the UWA channel is an unforgiving wireless medium that poses numerous challenges to reliable, high data rate and long-distance communications.

Four aspects of the UWA channel are of primary concern: ambient noise, transmission loss due to geometrical spreading and absorption, reverberation due to multiple paths, and Doppler spreading due to relative motion. Each of these must be considered in modeling the appropriate UWA channel.^{1,2} Multipath propagation, for instance, could restrict communication in the channel to non-coherent modulation schemes and low data rate transmission.

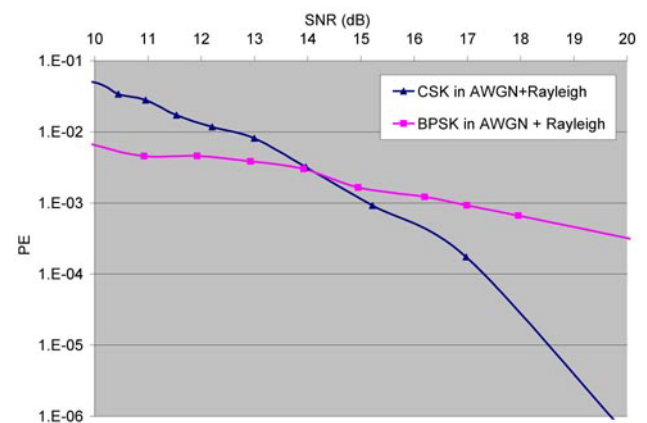


Figure 1. Binary chirp slope keying (CSK) has an advantage over binary phase-shift-keying (PSK) in the Rayleigh channel, in terms of probability of error (PE) as a function of signal-to-noise ratio (SNR).

In the past, underwater acoustic communications received much attention, mainly from the military, and the field was closely associated with submarine detection. In recent years, interest has shifted to more commercial applications. Today, various unmanned submersibles employ underwater communications systems. These include robots, remotely operated underwater vehicles (ROVs), and unmanned underwater vehicles (UUVs), which are replacing divers in performing a variety of offshore tasks.

As a spread-spectrum system, chirp slope keying (CSK) utilizes a data-modulated signal with its energy spread over a bandwidth that is much greater than the rate of information being transmitted.

Chirp slope keying

Chirp signals in digital communications were apparently originally suggested by M. R. Winkler³ in 1962 and then abandoned.

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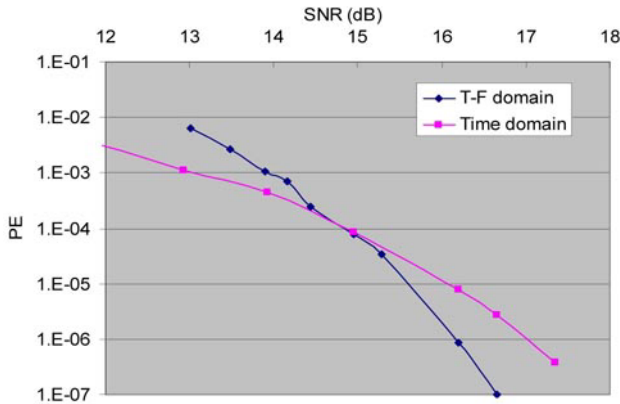


Figure 2. Probability of error versus SNR for BCSK in the AWGN channel with time and joint time-frequency receivers.

The idea is to use a pair of linear chirps that have opposite chirp rates for binary signaling. Binary chirp signals, or what Berni⁴ called linear frequency sweeping (LFS), compared favorably to frequency-shift-keying (FSK) and phase-shift-keying (PSK) in coherent channels. In non-coherent channels LFS was considered less appealing because of the requirement for a phase recovery system.

Our simulation results show considerable improvement in performance in the signal-to-noise (SNR) ranges of interest in performance when binary CSK is used instead of binary PSK in the Rayleigh fading channel.^{5,6}

A linear complex chirp signal may be modeled as in (1):

$$s_c(t) = A \exp \left[j2\pi \left(f_0 t + \frac{\mu}{2} t^2 \right) \right]. \quad (1)$$

The real part of $s_c(t)$ is used as the transmitted signal, with the frequency slope μ indicating the transmitted bit. In terms of maximum and minimum instantaneous frequencies, f_{max} and f_{min} , and the signaling interval T , an 'up' chirp is represented as in (2) while a 'down' chirp is represented by (3):

$$s_u(t) = A \cos \left[2\pi t \left(f_{min} + \frac{f_{max} - f_{min}}{2T} t \right) \right], \quad (2)$$

$$s_d(t) = A \cos \left[2\pi t \left(f_{max} + \frac{f_{max} - f_{min}}{2T} t \right) \right]. \quad (3)$$

The binary information stream $\{B_i\}$ selects the chirp pulses $\{p_i(t)\}$ to be transmitted at each signaling interval as follows:

$$p_i(t) = \begin{cases} s_u(t), & B_i = 1 \\ s_d(t), & B_i = 0 \end{cases}. \quad (4)$$

Results

Monte Carlo simulations were performed in the additive white Gaussian noise (AWGN) and the Rayleigh fading channels.

Figure 1 shows the advantage of CSK over PSK in the noisy Rayleigh fading model with a ratio of bandwidth to information rate of 100.

Clearly, for SNR above about 14.5dB, chirp slope keying performs better than standard phase shift keying in the simulated UWA environment.

The results shown in Figure 1 represent the performance for the standard coherent correlation receiver with perfect phase recovery. Joint time-frequency techniques may be used to gain performance advantages at the expense of computational complexity. This is exemplified in Figure 2, which gives results for CSK in the AWGN channel both for the standard time-domain correlation detector and for a joint time-frequency detector,⁶ which uses the Wigner distribution⁷ and the Radon transform. The Wigner distribution is used to obtain the frequency vs. time image spectrum of the received signal. The Radon transform, by projection of the image intensity along a radial line oriented at a specific angle, can then determine the slope, thereby finishing the demodulation process.

Conclusion and future work

Our brief discussion of chirp slope keying (CSK) suggests it is a promising alternative to ordinary modulation schemes for underwater acoustical communications. Accurate modeling of the UWA channel is necessary in order to accurately predict system performance. Further work in this area is needed. Investigation of joint-time frequency receivers also may prove useful, especially if efficient algorithms are designed to reduce the computational complexity.

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